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MEMORANDUM REPORT BRL-MR-3745

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PERFORMANCE MODIFICATIONS FOR AN AXISYMMETRIC LARGE BLAST SIMULATOR MODEL

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EDMUND J. GION
BRIAN P. BERTRAND

APRIL 1989

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U.S. ARMY LABORATORY COMMAND

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) BRL-MR-3745	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION US Army Ballistic Research Laboratory (BRL)	6b. OFFICE SYMBOL (If applicable) SLCBR-TB-B
7a. NAME OF MONITORING ORGANIZATION	
6c. ADDRESS (City, State, and ZIP Code) Aberdeen Proving Ground, MD 21005-5066	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Performance Modifications for an Axisymmetric Large Blast Simulator Model

12. PERSONAL AUTHOR(S)
Edmund J. Gion and Brian P. Bertrand

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM ______ TO ______		

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Blast, Shock Tubes, Blast Simulators, Varying Area ~~Shock Tubes~~, Blast Waves

(Mgm)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Modifications to the basic geometry and operation of the BRL Axisymmetric Large Blast Simulator (LBS) Model have been examined, to see if improvements can be achieved in its performance. The modifications tried were a) heating of the driver gas; b) operation with a discontinuous area change from diaphragm throat to driven tube; and c) operation with an enlarged throat at the diaphragm station. Performance gains over normal cold-gas operation were significant with driver gas heating and with the enlarged throat, modifications a) and c). Results using the discontinuous area change, rather than the present design with diverging nozzle opening to the driven tube, suggest that the modification is a viable design consideration for the full scale U. S. Large Blast/Thermal Simulator Facility.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL Edmund J. Gion	22b. TELEPHONE (Include Area Code) 301-278-4914 / 22c. OFFICE SYMBOL SLCBR-TB-B

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

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ACKNOWLEDGEMENTS

The authors wish to thank Messrs. R.L. McGill, W.B. Sunderland, and J. Rice--summer student--for their capable assistance and timely cooperation in the conduct of the experiments, which assured a continuing flow of results for analysis.

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1. INTRODUCTION

This report describes continued experimental work performed on the axisymmetric, single-driver, shock-tube model of a large blast simulator (LBS) located at the Centre d'Etudes de Gramat (CEG), France. The purpose of this work remains the same as that in the previous report: to provide data for comparison with computer codes, to assist in the design, and to assess modifications to a large blast thermal simulator (LB/TS) contemplated for the U. S.[1] In particular, a more extensive and better instrumented set of heated-driver gas tests was made. A few preliminary, heated-driver tests had been made earlier.[2] Also, tests were made without the diverging nozzle section following the nozzle throat/diaphragm station, opening discontinuously to the full-driven tube diameter. These discontinuous expansion tests were made to determine whether one could smooth the initial pressure spike noted in the pressure waveform at the lower shock pressure levels, when using the conical expansion section.

The last section presents a set of tests performed with the original converging/diverging nozzle, but with an enlarged throat, to give a driven-tube-to-throat-area ratio of 16 rather than the original ratio of 29, as for the CEG design. The objective for these last tests was to determine the performance gain over the original design in order to achieve shock over-pressures of up to 35 psi (240 kPa) and as an alternative to the engineering problems arising from driver-gas heating and from the construction and operation problems of a cold-driver facility. These questions and the work performed are discussed in the following sections.

2. LBS MODEL AND TEST PROCEDURES

The LBS model is the axisymmetric, 2-dimensional model constructed to 1:37 scale of the CEG multidriver facility.[3] For completeness, a sketch is shown of the internal geometry of the model. One design feature in particular should be noted: There is an annular plate that is removed above certain shock pressure levels and allows outside air to be entrained, resulting in an extension of the waveform's positive duration (corresponding to changes in weapon yield). This feature is not used in the tests, described in Sections 3 and 4, to facilitate computer modelled comparisons. The basic instrumentation consists of PCB piezoelectric pressure gages and Endevco semiconductor, four-bridge-wire, strain-gage transducers to monitor static and stagnation pressures along the driven tube and at the test station 7. The station numbers correspond to tube diameters down the driven

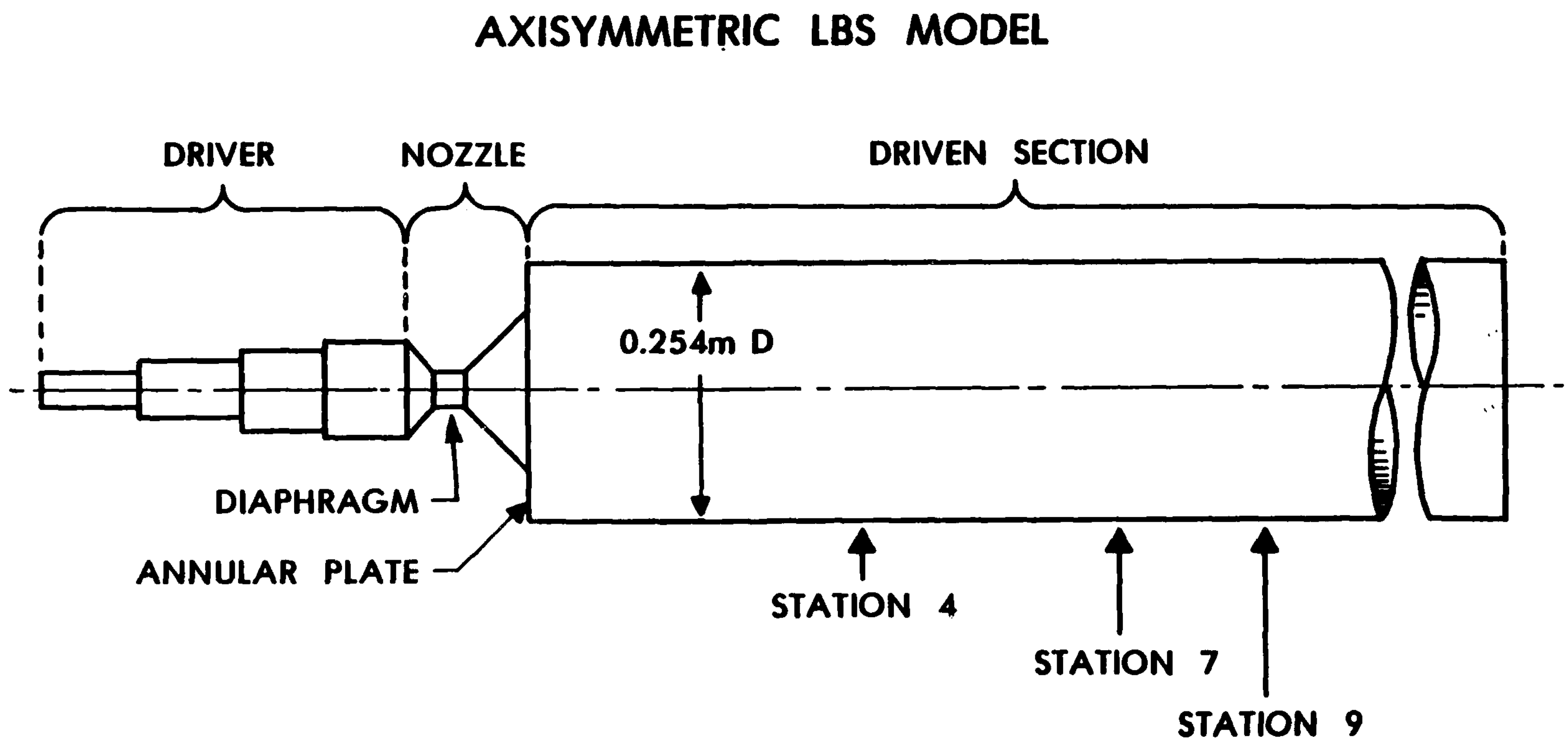


Figure 1. Axisymmetric large blast simulator (LBS) model. (Station numbers correspond to tube diameters down the driven tube.)

section measured from the nozzle exit as before.[1] Analog tape recorders acquire the pressure and other data, which are then digitized off-line for analysis.

3. HEATED DRIVER GAS TESTS

Heating of the driver gas offers two advantages over normal shock tube operation. It permits pressurizing the driver to more moderate levels for the same shock-pressure level and, hence, makes feasible less massive driver tubes, and it mitigates the disturbing effects of cold-driver gas arrival at the test station. A series of heated-driver gas shots was made to provide data and to establish performance for a complex geometry shock tube. The method of heating was reported in Reference 2.

Essentially, a number of resistance heater strips distributed about the driver tube periphery brought the driver walls and the contained driver gas to high temperature. For the present tests, Omega Corporation chromel-alumel thermocouples protruding approximately 2.54 cm into the interior volume monitored the driver gas temperature. This arrangement allowed for more confidence in the temperature read out over that used for the earlier, preliminary tests, in which the present thermocouples were unavailable. It is worth noting that the external, wall-mounted thermocouple, as used in preliminary experiments and retained here for a check on the previous data, gave driver-gas temperatures within 10-15° F of the interior-reading thermocouples. A divergence in readings occurred only during the inletting of gas, occasioning local temperature fluctuations that clearly are not followed by the exterior walls.

A temperature range of 423-533 K (300-500° F) was used. Shots are listed in Table 1, and Figure 2 illustrates the LBS Model performance with heated driver gas. Shown for comparison are results from previous runs with cold driver gas.[1,3] This series of shots was performed with annular plate in place, preventing entrainment of outside air, to permit more convenient computational modelling of the tube geometry for theoretical comparison. The increased performance gain using the heated driver is clearly evident. At the highest shock pressure of 225 kpa (33 psi) the driver pressure required, when $T4/T1=1.75$, is only about one-half that for the cold driver.

A calculation for the driver gas temperature ratio and flow conditions required for "matched" conditions across the contact surface has been made by Pearson,[4] using the BRL QID code. Essentially, a trial and error procedure was used to find the smoothest dynamic pressure trace in the region of the contact surface. This gave the flow conditions necessary to achieve matched density across the interface.

TABLE 1. Heated Driver Gas Flow Conditions.

Shot no.	P4/P1	ΔP2, psi	ΔP2, kPa	P2/P1	T4/T1
2	106	32.6	225	3.21	1.75
4	80.2	28	193	2.89	.75
5	90.7	30.5	210	3.06	1.75
6	77.7	26.8	185	2.8	1.75
7	58.3	25.4	175	2.71	1.75
8	61.7	23.2	160	2.57	1.75
9	50.4	18.9	130	2.27	1.75
19	31.4	13.5	93	1.91	1.75
20	20.6	10.2	70	1.69	1.75
22	167	41	283	3.79	1.75
23	132	34.8	240	3.37	1.75
10	56.9	20.6	142	2.4	1.59
11	68.6	25.4	175	2.71	1.59
12	45.9	18.1	125	2.22	1.59
13	54.4	20.3	140	2.37	1.59
17	22.6	10.9	75	1.73	1.59
18	33.4	14.5	100	1.98	1.59
14	38.8	16.7	115	2.13	1.41
15	47.6	18.9	130	2.27	1.41
16	60.8	21	145	2.42	1.41

Note: P4/P1 and T4/T1 are driver gas pressure-temperature ratios, P1 and T1 being the ambient; ΔP2 is the shock over-pressure; P2/P1 is shock pressure ratio or shock strength.

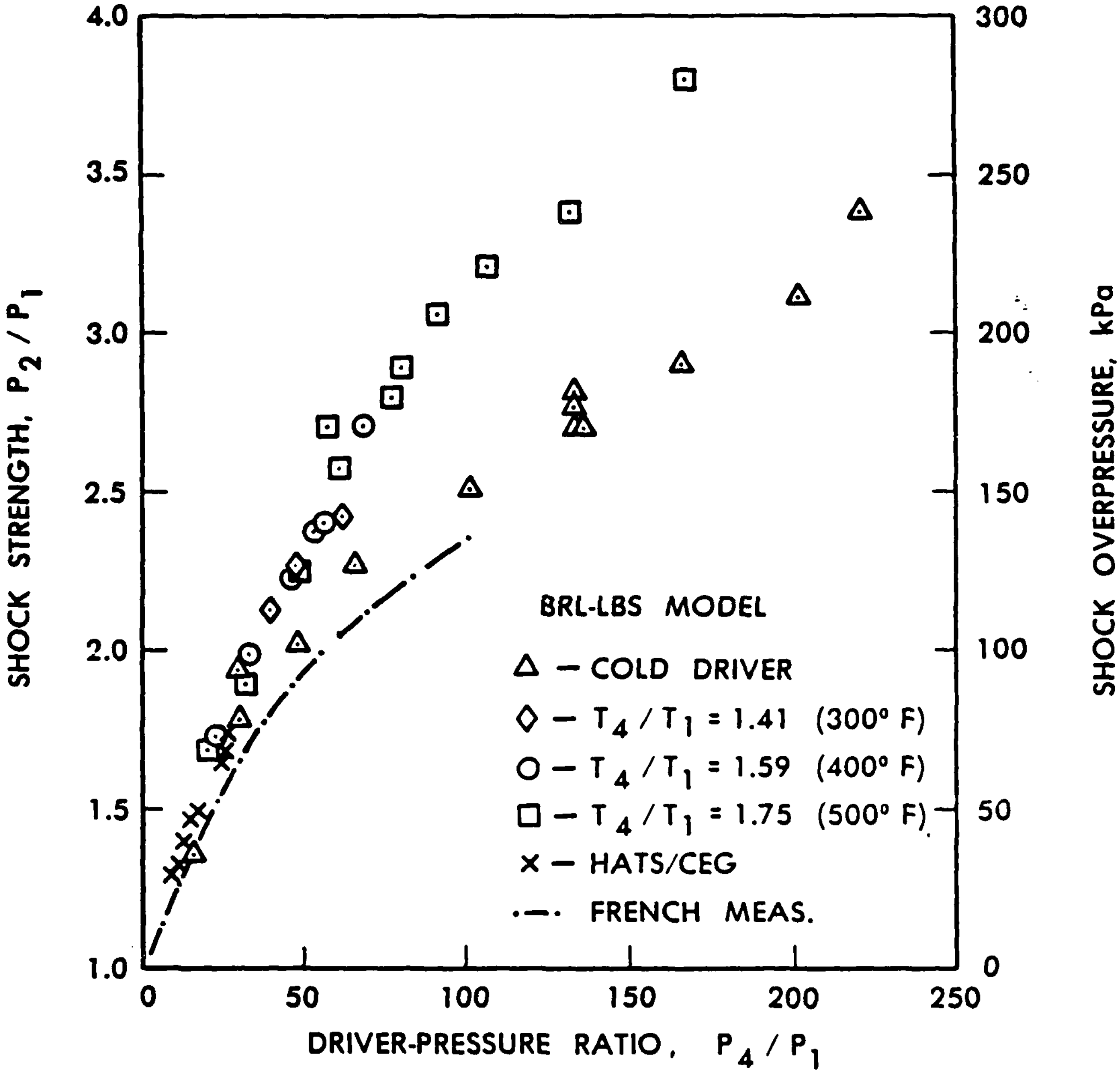


Figure 2. Heated driver gas performance of LBS model and comparisons with unheated driver gas data.

The use of natural bursting of diaphragms by overpressure and the limited selection of diaphragms available prevented achievement of precisely the flow condition believed necessary. However, achievable shots with flow conditions bracketing the matched condition were believed sufficient to check the theoretical points; for driver/shock pressures to the high side of that predicted for a given temperature matching, the stagnation pressure trace would respond to the higher temperature, lower-density-shocked gas, then lead to a "jump" in the trace indicating the colder, higher-density driver gas flowing over the gage. For the opposite situation of driver/shock pressure to the low side for matching, the driver gas will be warmer, and less dense than the shocked gas; hence, a drop in the stagnation pressure trace would signal the arrival of driver gas following the shocked gas.

The actual records do not, unfortunately, reveal such detail because of the inherent noisiness of the traces. As an example, the stagnation traces for the shots grouping about the matched condition P4/P1=87 (ΔPs=175 kpa) and T4/T1=1.75 (re Pearson[4]) are shown in Figures 3a-e. The flow parameters for these shots are found in Table 1. The shots are shown in descending order of shock strength, with shot 85-7 as the "matching condition." Shots 85-5 and -6 are to the high side, and spikes occurred some 4 msec after shock arrival of these two shots. Shots 85-8 and -9 are to the low side of the matched condition. However, it is not possible to detect any drop in pressure level with the expected contact surface arrival within 5 msec after the shock. These tests, plus others grouping about Pearson's "matched" flow conditions, are graphed in Figure 4 as the open symbols. Pearson's predicted points are the closed symbols, at the T4/T1 as specified on the graph. From these few data, a marked discrepancy can be detected between the predicted shock pressures and the experimentally determined shock pressures at matching conditions for a given T4/T1. The reason for this is not clear, although the agreement between predicted and experimental cold-driver results is reasonable.[1] Further computational work is planned, including use of a new 2D BRL code.

4. DISCONTINUOUS AREA FOLLOWING NOZZLE THROAT

The pressure traces from a low-level shot series reported in Reference 1 are reproduced in Figure 5. One may discern evidence of a leading pressure "spike" in the waveforms, as was seen in the full-scale CEG results, a low-level example from which is shown in Figure 6.[3] The spike is typically about 30-msec width in the full-scale facility, and it corresponds to the LBS Model's spike width when scaled by the 1/37 factor. The leading pressure spike is also noted in the LBS model computations with the BRL QID code.[1,5]

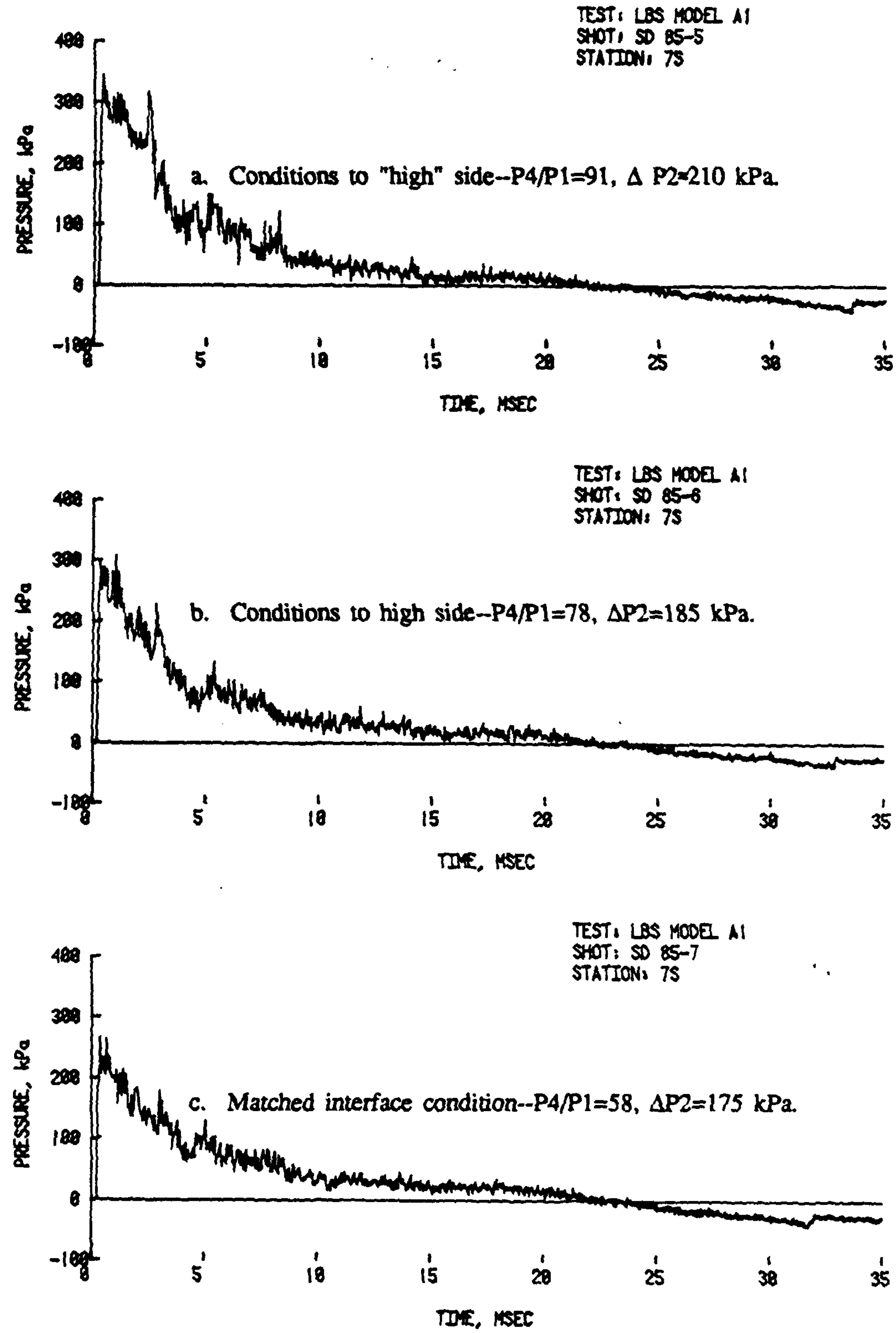
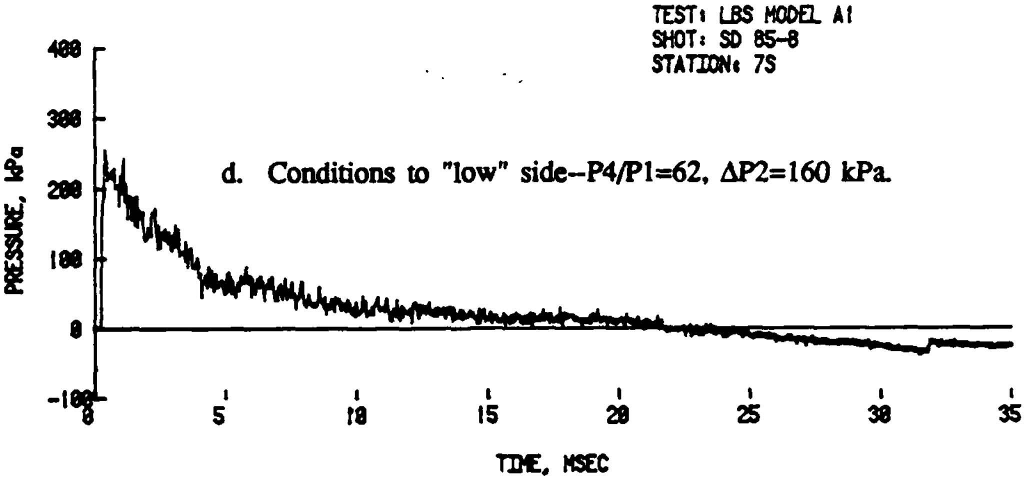
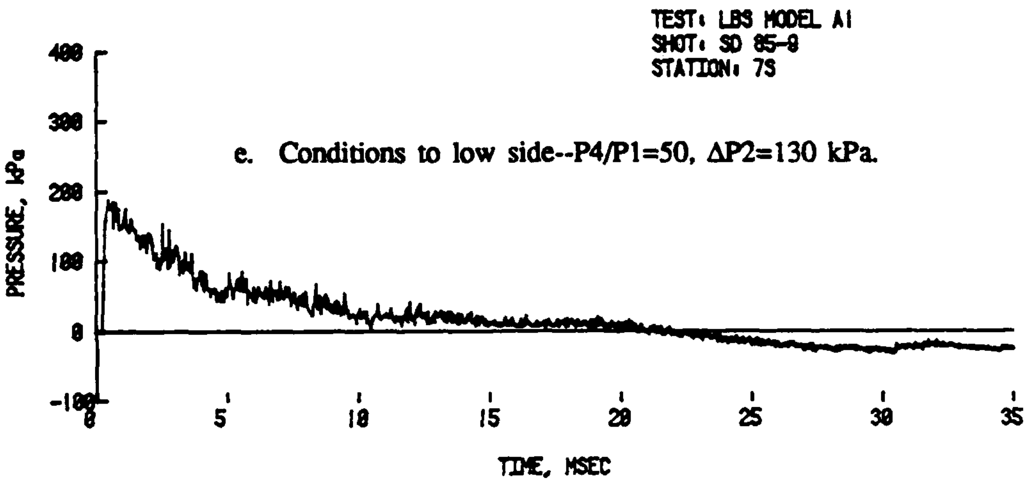


Figure 3, a-e. Stagnation pressure traces at conditions grouping about interface matched conditions, for T4/T1=1.75.



d. Conditions to "low" side--P4/P1=62, ΔP2=160 kPa.



e. Conditions to low side--P4/P1=50, ΔP2=130 kPa.

Figure 3. (Concluded)

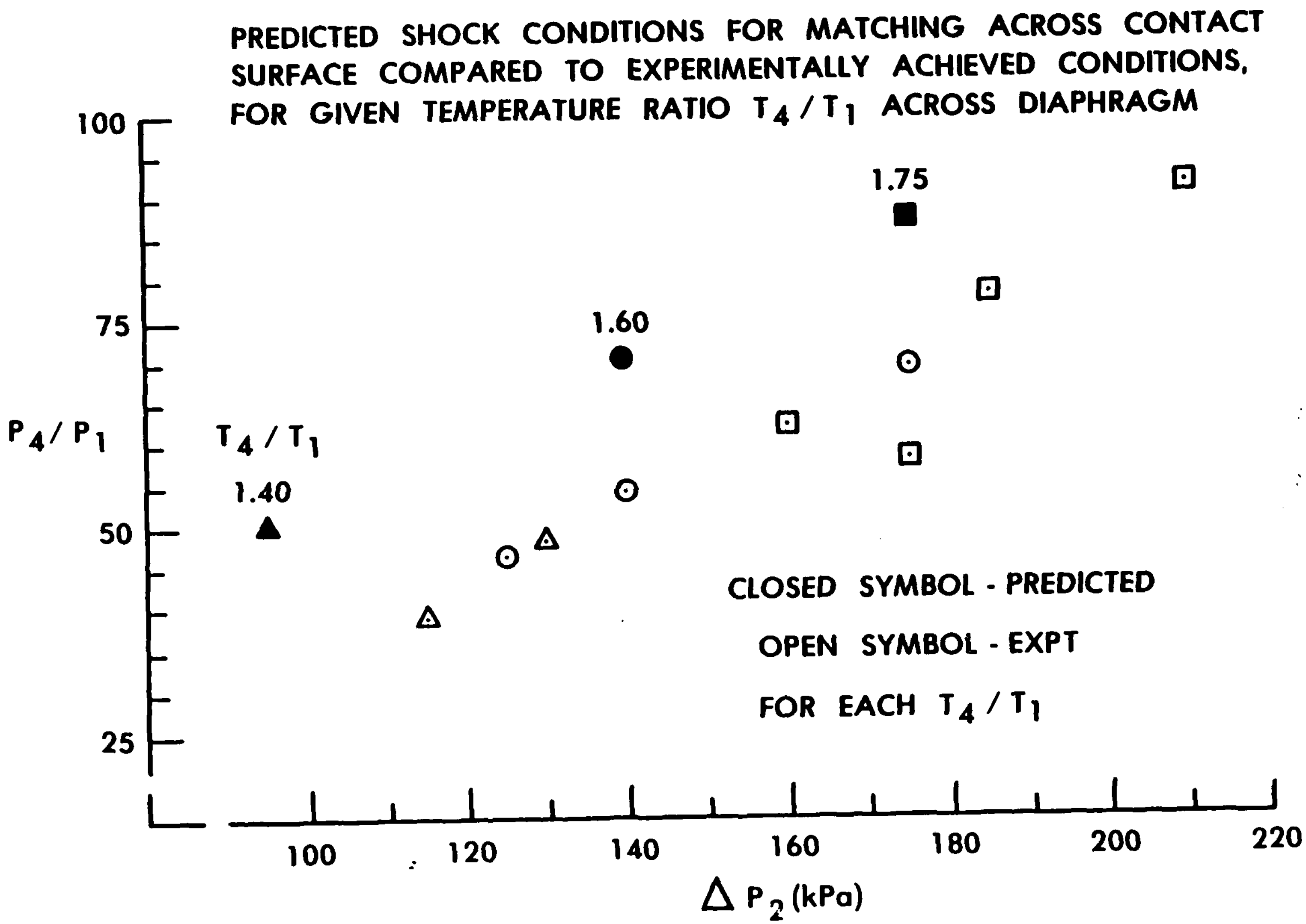


Figure 4. Selected interface matching results from Pearson and from present work.

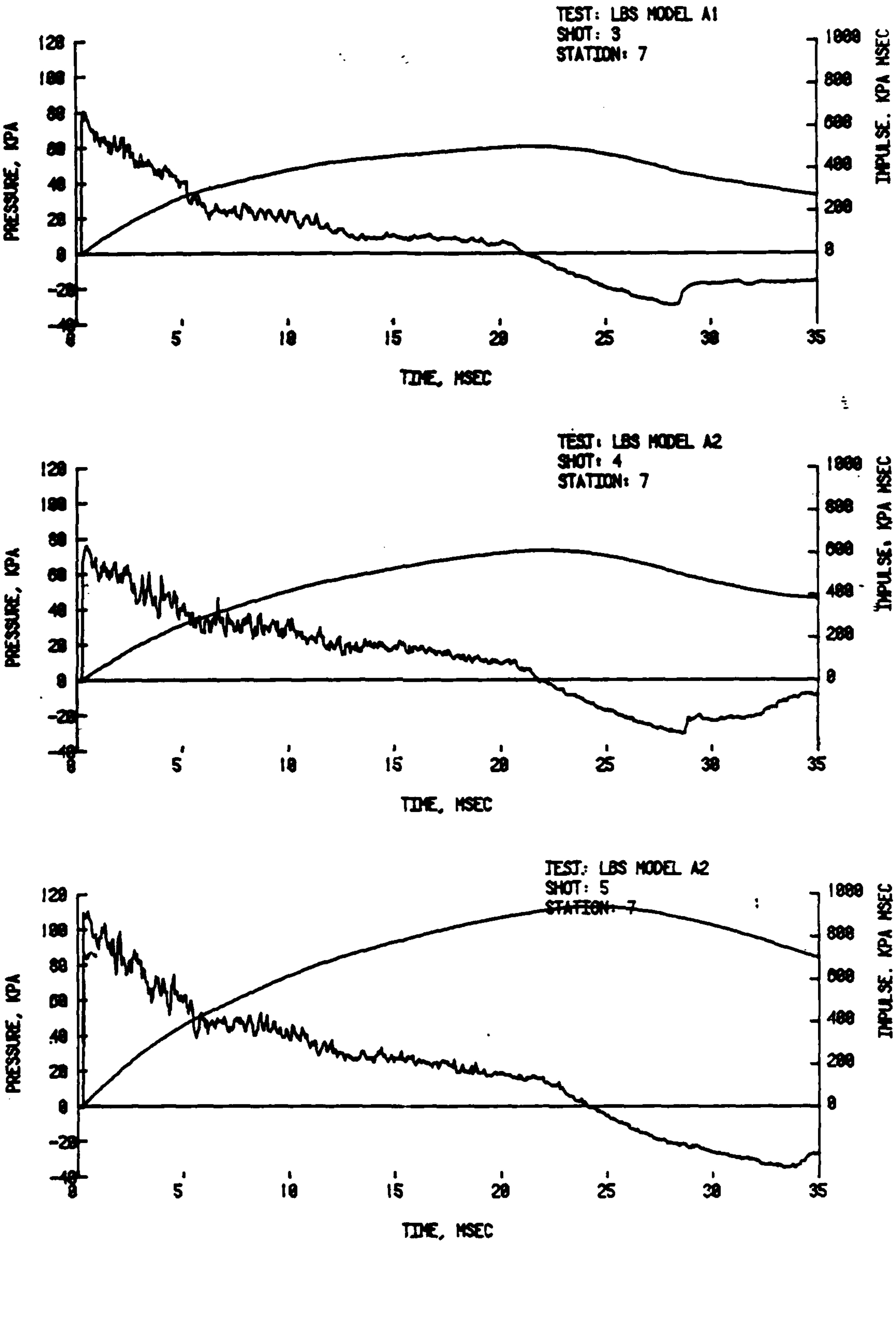


Figure 5. Low level shot series with leading pressure spike.

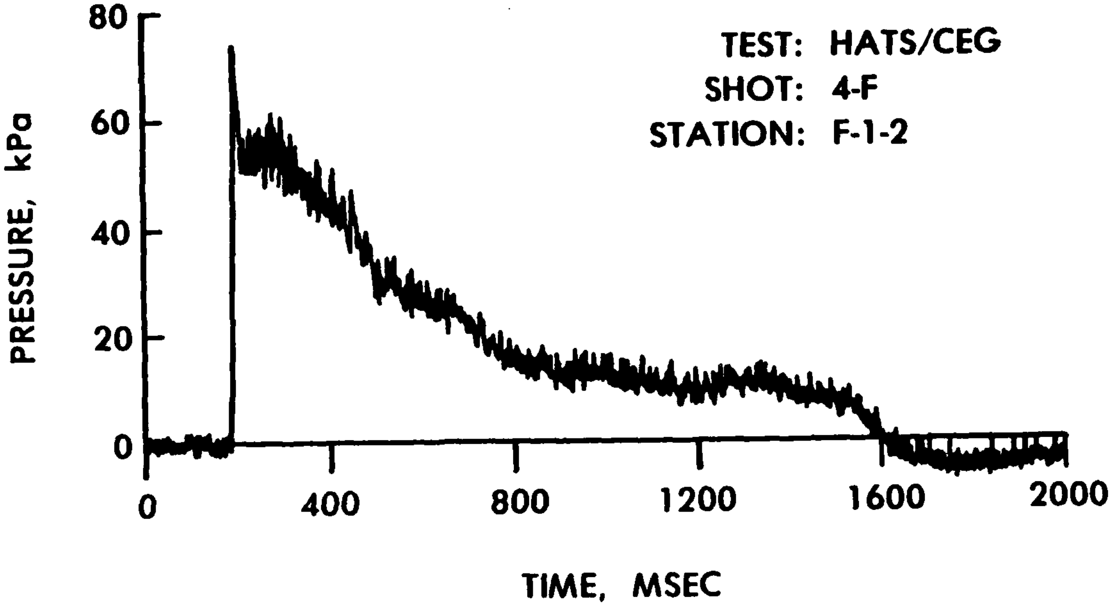


Figure 6. Typical low level pressure trace from full scale CEG facility.

Figure 7 is a figure reproduced from Reference 5 showing how a change in nozzle configuration with respect to the driven tube can influence the amplitude of the spike. Apparently, a nozzle opening to the full driven tube diameter induces a more severe spike, at all nozzle half angles considered, than the LBS Model nozzle, which opens only partially, then forms a discontinuous area jump to the driven tube area. The evidence suggests that the spike might be avoided by removing the divergent nozzle and discontinuously opening the throat of the nozzle to the driven tube area.

As an experimental check, an assembly without divergent nozzle, the nozzle throat opening directly into the driven tube, was installed in the LBS Model, and some low shock pressure tests were performed (Table 2). The annular plate was kept in place (no air entrainment) to facilitate the comparison with the computer model. Figure 8 shows results, for stations grouping about the test station 7, for two shock conditions. The smoothing of the initial spike, if any, is somewhat questionable in view of the noisiness of the traces. However, the waveforms are not noticeably worsened by the use of the sharp area change to the driven tube. This finding may obviate the need for a diverging nozzle section following the diaphragm throat, with consequent cost savings in construction. This conclusion should be checked in the new BRL Multi-Driver Shock Tube facility. Without refinement of the instrumentation for these shots, further conclusions at this time cannot be made with regard to spike formation.

5. TESTS WITH ENLARGED THROAT

Some tests were performed with the LBS Model's throat enlarged to 6.35 cm (2.5 in) from the original 4.72 cm (1.86 in). Enlarging the throat tends toward the 1:1 throat area ratio of the simple straight-shock tube and, thus, should give a stronger shock for a given driver pressure. Desired performance levels could be achieved at lower maximum driver pressures, which cause less stress in tubing walls and require less critical welds in overly thick tubing. The modification leads to a throat-to-driven-tube-area ratio of 1:16, compared to the original LBS Model and CEG Facility ratio of 1:29. Demonstration of sufficiently enhanced performance with the enlarged throat area would support a useful design consideration for the full-scale LB/TS Facility.

Thus, the converging-diverging throat of the LBS Model was bored out to the requisite throat-area ratio. The axial length scale for the throat naturally was destroyed, but this feature was deemed not essential for the interpretation of the results. The results and the flow conditions for a small set of tests at the higher shock pressure levels are exhibited in Table 3. Results are also plotted in Figure 9 to show comparison with previous data. The enhanced performance is clearly

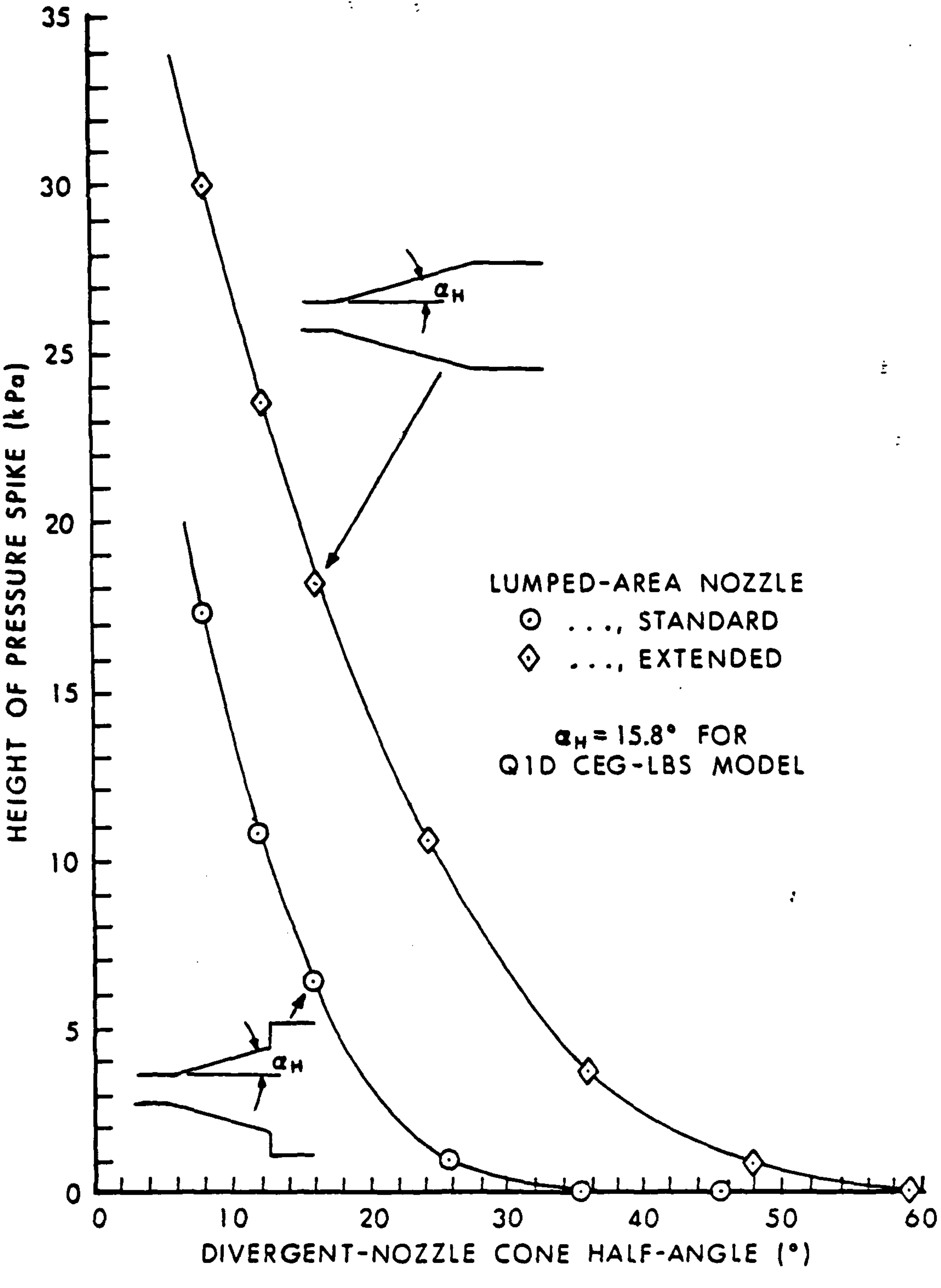


Figure 7. Graph depicting calculated pressure spike amplitude related to cone half-angle (Ref. 5) for a 35-kPa (5psi) shock.

TABLE 2. Low-Level Shot Series with Discontinuous Area Opening from Diaphragm Throat.

Shot no.	P4/P1	ΔP2, psi	ΔP2, kPa	P2/P1
25	27.9	10.4	72	1.70
26	41.6	13.3	92	1.89
27	51.2	14.1	97	1.94
28	50.5	14.2	98	1.95
29	88.1	20.6	142	2.38
30	115	24.2	167	2.62
31	135	27.6	190	2.85

TABLE 3. Flow Conditions and Results for Enlarged Throat.

Shot no.	P4/P1	ΔP2, psi	ΔP2, kPa	P2/P1
32	21.2	12.2	84	1.82
33	34	17	117	2.14
34	39	18.9	130	2.27
35	83	28.3	195	2.89
36	108	32.2	222	3.16
37	113	33.4	230	3.24
38	114	32.6	225	3.19
39	133	34.4	237	3.31
40	161	35.5	245	3.41

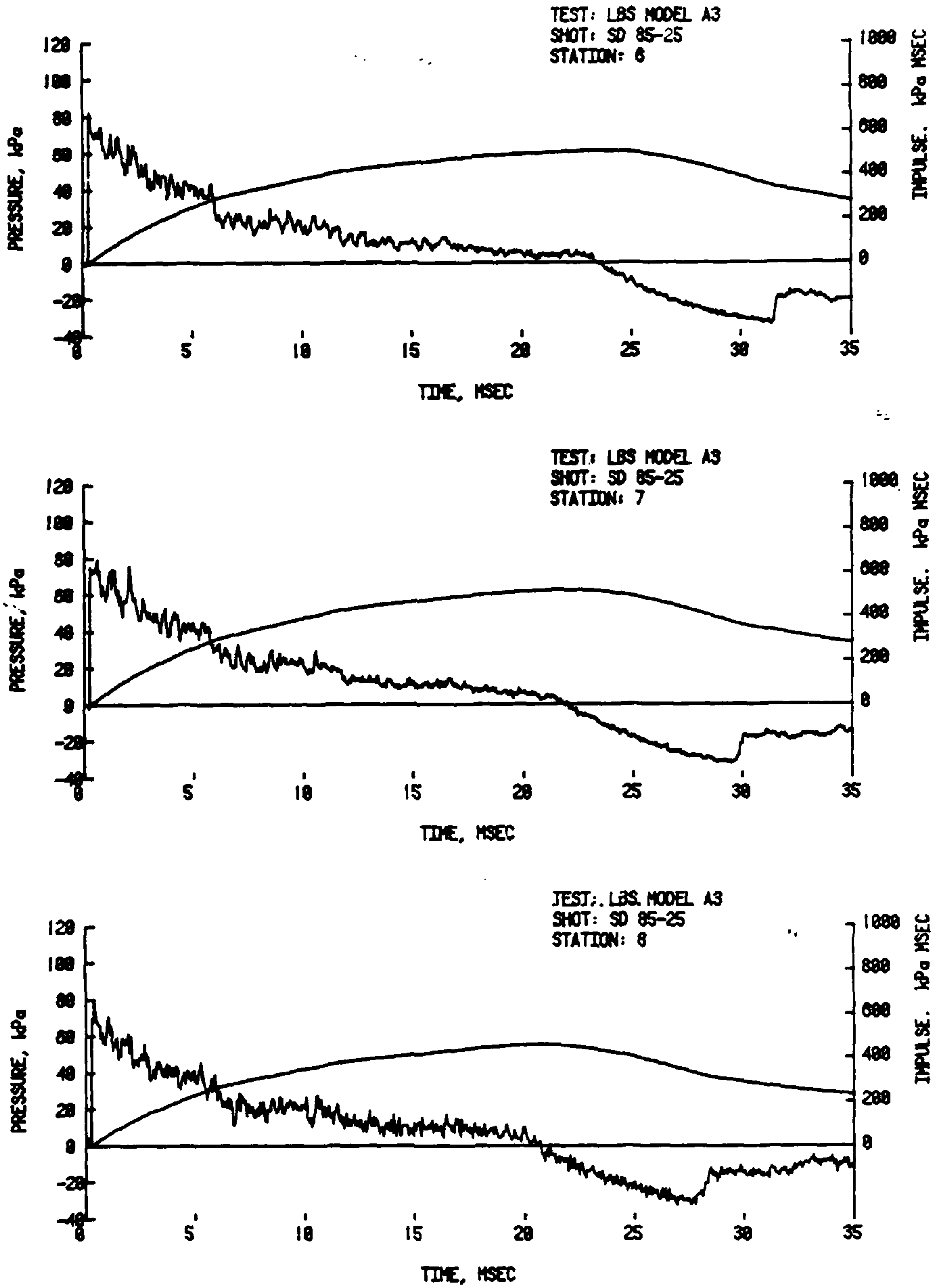
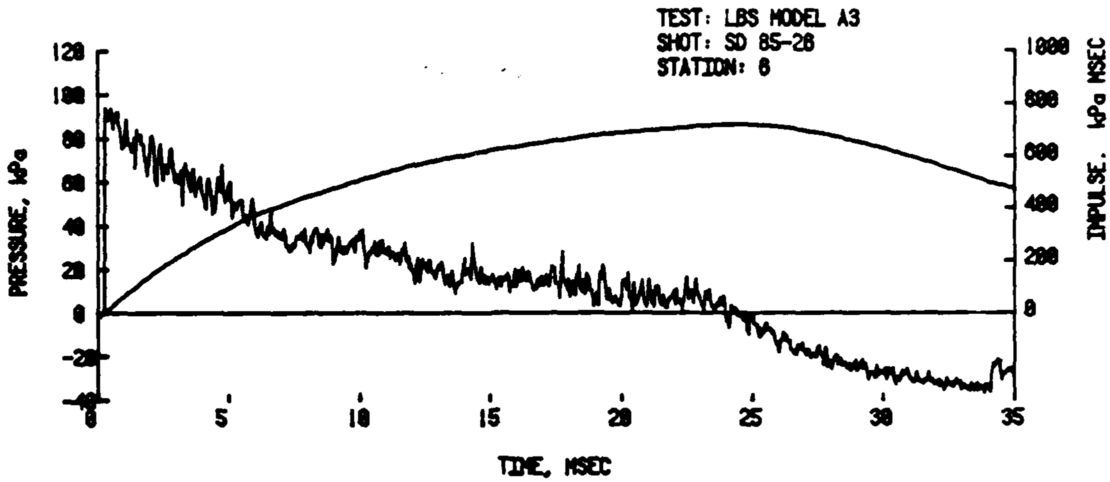
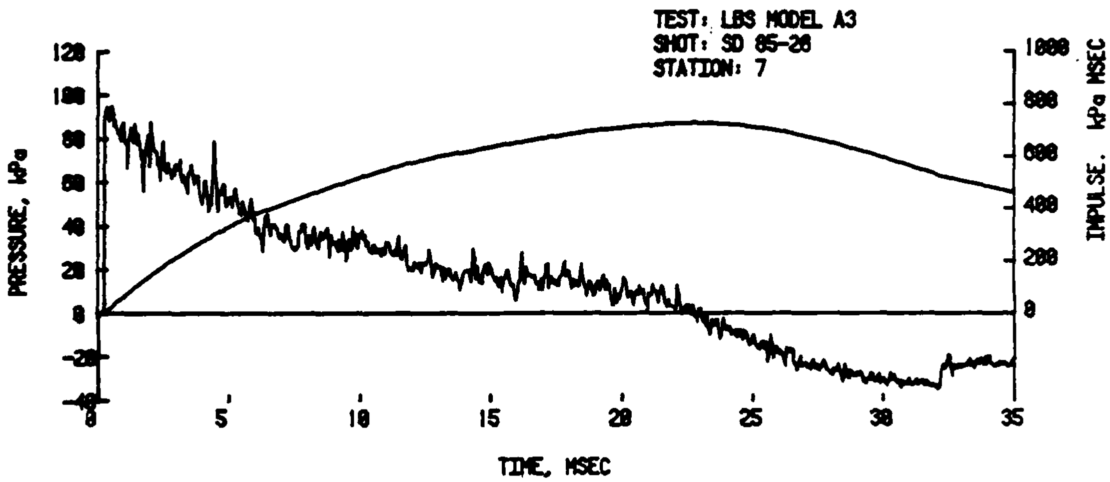


Figure 8a. Pressure traces for discontinuous throat area opening to driven tube. Shock overpressure 80 kPa





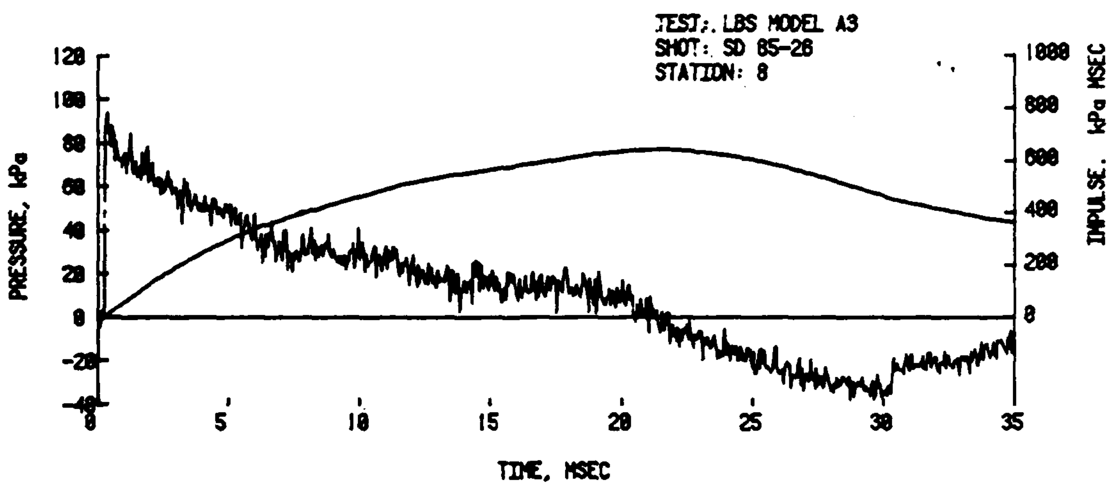


Figure 8b. Shock overpressure 95 kPa.

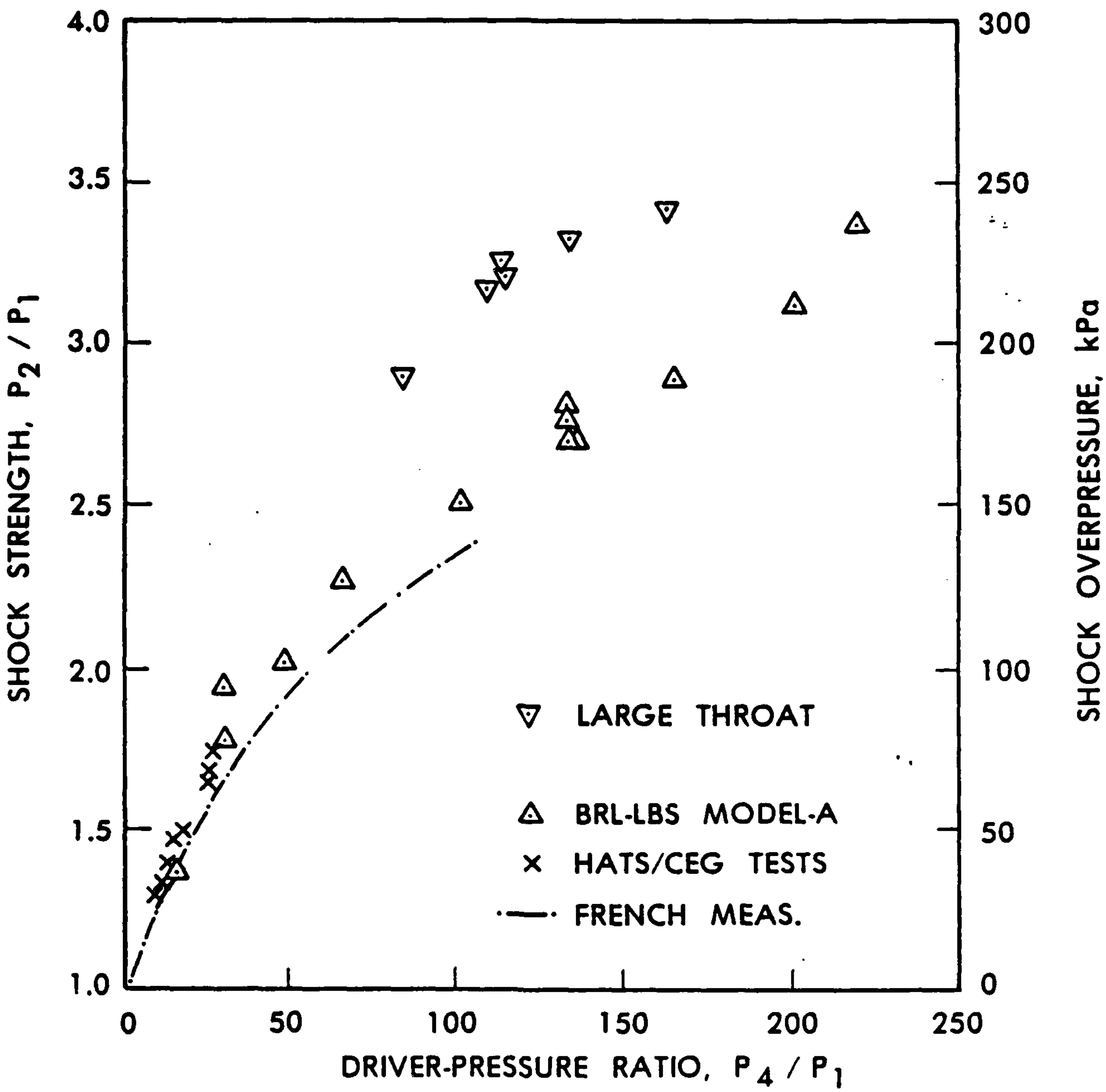


Figure 9. Results from enlarged nozzle throat and comparisons with data from standard nozzle throat.

observed. The levels are comparable to those of the heated-driver-gas tests at T4/T1=1.75 (T4=500° F), previously obtained. However, with the present unheated driver gas, one must expect disruption of tests in which drag is a sensitive factor, when the cold driver gas arrives at the test station, unless one moves the test station farther downstream to mitigate such effects. Then, the shock pressure levels may decay to levels below those desired.

6. CONCLUSIONS AND SUMMARY REMARKS

In previous reports concerning the operation of the 1/37 scale LBS Model,[1,2] the model performance was determined for shock overpressures to better than 200 kpa (30 psi), and various properties of the produced flow were examined. Detailed comparisons were made with predictions obtained from a new BRL QID code to assess the code's ability to predict flows from a complex geometry shock tube. In this report, further experimental work has been performed with the objective of looking at modifications to the basic geometry or operation of the LBS.

Specifically, tests with heated driver gas were performed. Appropriate heating produces higher strength shocks at lower driver pressures and matches the dynamic pressure across the contact surface (driver/driven gas interface). Important operational benefits are gained, together with a lighter construction. Some tests using a discontinuous nozzle and throat-to-driven-tube opening were made in an effort to remove an initial pressure spike noted in both the model and the full-scale facility test results, as well as in the computed BRL-QID simulations. The experimental results were inconclusive in this regard, due to noisiness of traces. However, the results did suggest that flow quality was not worsened when the divergent nozzles were omitted. Thus, material costs and operating efficiencies could be affected by using such discontinuous nozzles. Tests in the new BRL Multi-Driver Shock Tube model should also be done to verify that the flow quality is indeed maintained for the seven area discontinuities in that configuration. Finally, a few tests with enlarged throat diameter (1/16 throat-driven-tube area versus the original 1/29 scale) showed performance enhancement comparable to that achieved with the driver gas heating experiments.

7. REFERENCES

1. Hisley, D.M., Gion, E.J., and Bertrand, B.P., Performance and Predictions for a Large Blast Simulator Model, BRL-TR-2647, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, April 1985.

2. Gion, E.J., Hisley, D.M., and Bertrand, B.P., Experimental and Theoretical Performance of Large Blast Simulator Models, Proceedings, Ninth International Symposium on Military Applications of Blast Simulation, Oxford, England, 23-27 September 1985.

3. Teel, G., Unpublished data from HATS tests, CEG, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1981.

4. Pearson, R.J., Private communication, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 15, 1987.

5. Opalka, K.O., and Mark, A., The BRL-Q1D Code: A Tool for the Numerical Simulation of flows in Shock Tubes with Variable Cross-sectional Areas, BRL-TR-2763, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, October 1986.

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